

Damage and yield change in cocoa crops due to harvesting of timber shade trees in Talamanca, Costa Rica

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Abstract A computer model was developed for the economic analysis of the damage caused to cocoa plants (*Theobroma cacao*) due to the harvest of timber shade trees (*Cordia alliodora*), based on field estimations from cocoa farms in the indigenous region of Talamanca, in the south east of Costa Rica. An economic cost-benefit analysis was carried out considering cocoa planting densities, yields, timber volumes and both cocoa and timber prices. Damage to cocoa plants was quantified in terms of severity levels and then translated into yield losses and their corresponding economic values. From the 49 harvested timber trees observed, 196 cocoa plants were affected, of which 4% required replanting and 38% coppicing. Tree trunks were involved in 55% of the damage cases (109) and tree crowns in 45% (89). Nevertheless, the revenue obtained from timber sales

easily offset the costs of damage to the cocoa crop. The economic analysis showed that on average, the net gain derived from timber harvesting was around US\$316 per tree. For all considered scenarios, the timber market price that would balance discounted costs and benefits to zero ranged between US\$22 and US\$66 m⁻³ (current market price for *C. alliodora* is US\$128 m⁻³). There would be lower margins due to higher costs of cocoa damage in high yielding, high price cocoa scenarios. However, the study shows that damage due to tree felling should not be a major objection of farmers to the use of timber shade trees in cocoa farms even in these scenarios.

Keywords *Cordia alliodora* · *Theobroma cacao* · Agroforestry · Shade tree harvest · Timber production · Cocoa damage · Economic analysis · Indigenous people · Costa Rica

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Introduction

Cocoa or cacao (*Theobroma cacao*) is among the major perennial crops worldwide and have enormous economic importance for developing countries in the humid tropics (Beer et al. 1998). Cocoa, together with other widely grown perennials such as coffee (*Coffea* spp.), tea (*Camellia sinensis*), black pepper (*Piper nigrum*) and vanilla (*Vanilla fragans*), is usually

grown under shade trees (Beer 1987; Willson 1999). Very often, timber trees form an important component of the shade strata in these systems. Some common examples of timber trees in cocoa shade canopies include *Cordia alliodora* (Somarriba and Beer 1987; Somarriba et al. 2001), *Cedrela odorata* (del Amo and Ramos 1993; Guevara 1988), *Triplaris cummingiana* (Bentley et al. 2004; Mussak and Laarman 1989) *Terminalia ivorensis* (Lamb and Ntima 1971) and *Swietenia macrophylla* (Browder et al. 1996; Gesta 1999; Medina 1987; Teixeira 1999). Diversification of cocoa plantations (e.g. by retaining and managing timber trees) increases stability in farm income and lowers financial risk (Ramirez et al. 2001); it may also help to conserve biodiversity (Schroth and Harvey 2007).

Tree tending and removal (for timber or to regulate shade) is a crucial part of shade management. Many hypothetical planting strategies and management regimes have been proposed by agroforesters in order to efficiently reduce crop damage during harvest and removal. These proposals often assume that farmers will renew their crops following a clear-cut harvest of the tree component (Beer and Heuvelodop 1987; Heuvelodop 1987). However, small farmers do not usually plant their trees in concordance with the establishment of the cocoa. Most times, farmers only have to promote volunteer tree seedlings from the profuse natural regeneration (Bentley et al. 2004; Mussak and Laarman 1989; Somarriba and Beer 1987). These trees are then felled selectively and irregularly according to farm household needs. As a result, the tree component is often uneven-aged and intermixed with the crops beneath and the time of crop renewal does not necessarily coincide with the harvest of timber. Consequently, whenever perennial crops are planted under timber shade trees, there is a high probability of damage to the crop plants due to tree felling and extraction.

The potential damage to cocoa plants and other perennial crops is of primary concern for most farmers and is the most frequently cited objection to initiatives aimed at promoting the use of shade and timber trees (Mussak and Laarman 1989). In coffee plantations, however, the harvest and extraction of laurel (*C. alliodora*) trees cause little damage to coffee plants and the additional income from timber sales could easily offset the limited damage experienced (Somarriba 1992). However, this may not be

the case for cocoa, since it tends to have a longer economic life and forms a more brittle and permanent structure than coffee and thus recovers more slowly from physical damage (Beer et al. 1998). Nevertheless, there is no solid data available on damage inflicted on cocoa that could potentially justify the use or rejection of timber trees in cocoa farms.

This study was carried out on 11 cocoa farms in the indigenous region of Talamanca, South-East Costa Rica to: (1) describe and quantify the damage caused by the harvesting of laurel (*C. alliodora*) to cocoa crops, and (2) develop a computer model to evaluate the economic impact of such damage under several biological and economic scenarios. Several authors have pointed out the characteristics of laurel that make it a suitable component of cocoa and coffee farms (Bentley et al. 2004; Greaves and McCarter 1990; Somarriba and Beer 1987; Somarriba et al. 2001).

Growth, development and yield of cocoa

The growth and development of cocoa is of great relevance for this study to understand the effects that damage due to tree felling can have on its physiology. The growth of cocoa is determined by a series of intervals and it has a tree architecture classified as Nozeran's model¹ (Hallé et al. 1978). Initially, the stem develops an orthotropic (vertical) axis up to about 1–1.50 m in height with a 3/8 phyllotaxy. After 18 months of age, growth of the trunk is interrupted by the degeneration of the terminal bud and branches develop in a set jorquette, which usually comprises 4–6 primary branches that form the framework of the tree. Secondary, tertiary and even quaternary branches develop from the primary branches to form the tree crown. However, cocoa has other orthotropic branches called chupons or suckers immediately below the jorquette that develop similarly to the main stem for another 1–1.50 m followed by development of another jorquette. In the wild, this pattern

¹ The model's architecture is modular and determined by an orthotropic, sympodial trunk, each unit of the sympodium bearing a distal tier of plagiotropic branches, which have a leaf arrangement that differs from that of the trunk. Growth of both trunk and branch axes may be rhythmic or not. Branches can be sympodial or monopodial and flowering is cauliflorous.

can be repeated another three or even four times (Wood 1975). In the case of managed plantations, the cocoa is generally pruned down to a single stem by removing all the suckers that come out from below the first jorquette (Mossu 1992).

When grown from seed, the cocoa tree is fully developed by the age of 10 years, but cocoa becomes productive well before that time. There is some controversy of when it first produces fruit. According to Wood (1975), where climate and soil allow continuous growth, jorquette formation will be within 6–9 months of planting. The crowns of adjacent trees will then meet by 18 months (at 3 × 3 m spacing). Wood (1975) estimated that the first crop would then be available towards the end of the second year and certainly in the third year. Mossu (1992) set the year of flowering and fruiting from the third to the fourth year and Young (1994) gave a wider range of between 3 and 5 years, depending on the local conditions and variety. Cocoa is cauliflorous, which means that the flowers develop on the older parts of the trunk and branches. Therefore, most of the fruits in cocoa are developed around the trunk and to a lesser extent on older branches such as those forming the jorquette. These fruits are called pods and contain 20–50 seeds (Willson 1999).

Quiroga-Gómez (1972) described the production pattern for cocoa in the environmental conditions of the Atlantic Zone of Costa Rica. The first cocoa harvest took place at 4 years, followed by a well-defined biannual oscillation. Commercial production of cocoa was estimated to start between 4.5 and 7 years of age, depending on the breeding material used and showed no tendency to decrease during the first 9 years, instead, there was an oscillation plotted around a straight line parallel to the time axis. Following Wood's assumptions (1975), the first crop of cocoa is gathered in the third year and it will keep increasing for the following 4 or 5 years until it reaches a maximum at 8–10 years after planting. Once it reaches that peak, cocoa is expected to maintain those yields until 20 years of age and then decline gradually to commercially unviable levels. The economic rotation for cocoa is estimated at 25–30 years of age, when yields may decline and replanting becomes necessary. If cocoa is coppiced, the tree starts producing fruit at an earlier stage, probably in the second year after coppicing and produce similar yields or even higher in the first few

years (Aranzazu 1992). Damage of primary branches also reduces yield provisionally, due to crown loss and decrease in leaf area.

Methodology

Damage to cocoa plants was classified into six severity levels, starting from the most severe to the least severe as follows: (1) uprooted tree, 100% crown loss (requires replanting); (2) snapped off or all primary branches damaged, 100% crown loss (requires regeneration from stump i.e. coppicing); (3a) primary branches damaged, 75–99% crown loss (very heavy pruning); (3b) primary branches damaged, 50–74% crown loss (heavy pruning); (4a) secondary branches damaged, 25–49% crown loss (moderate pruning) and (4b) secondary branches damaged, 0–24% crown loss (light pruning). Crown loss was estimated based on the proportion of primary branches remaining after damage in relation to the total number of branches present originally (i.e. if three out of the four primary branches were damaged this would be classified as level 3a). This damage was referred to as biological damage and was measured by counting the number of cocoa plants at each damage level (i.e. tally counting). The biological damage data was then used to calculate cocoa yield losses, which were then translated into an economic value. This will be explained further in more detail.

Location and characteristics of the experimental area

The study sites were located in eleven selected farms in five communities of the Talamanca-Bribri Indigenous Reserve, in the South-East of Costa Rica, adjacent to the border with Panama (9° 21'–9° 39' N 82° 50'–83° 50' W). The mean annual temperature varies between 24 and 27°C and precipitation is approximately 2,500 mm y⁻¹. Sites are at elevations <200 m; soils are classified as Inceptisols (Cambisols), deriving from alluvial deposits of volcanic materials deposited over sedimentary rock (Somarriba et al. 2001).

A typical indigenous farm in Talamanca is 11 ha in size, with 4 ha under natural forest with variable degree of fragmentation and selective timber extraction, 4 ha of fallow, 1.5 ha of shaded cocoa, 1 ha of organic banana and 0.5 ha in patios and home garden

Table 1 Area, age, planting density, management level and slope of cocoa farms, and number of felled *Cordia alliodora* timber trees used for estimation of damage to cocoa trees

	Farm	Area of cocoa (ha)	Age (years)	Cocoa planting density (plants ha ⁻¹)	Degree of management	Slope (max/min, %)	Trees felled
Talamanca, Costa Rica 2001	AM	2.0	40	465	Good	0	8
	AP	4.1	40	506	Medium	0–10	9
	CP	2.0	20	470	Poor	15–20	2
	CM	4.0	40	468	Poor	5–30	4
	DM1	0.5	9	322	Good	0	3
	DM2	0.6	25	431	Medium	0	4
	JL	0.6	30	526	Poor	0	1
	LM	0.3	50	383	Very poor	0	5
	RM	1.0	30	278	Medium	0	2
	SM	4.9	50	606	Good	0–10	8
	VS	8.4	25	479	Good	0	3
	Average	2.6	32	449		Total	49

around the house. However, it is very common to see both cocoa and banana intercropped under the shade strata. Annual crops are grown on an estimated 4-year rotation of shifting cultivation by slashing and burning young fallow within the farm (Guiracocha et al. 2001). Abundant natural regeneration of valuable timber species (such as *C. alliodora* and to a less extent *C. odorata*), occurs in cocoa and banana plantations (Suárez 2001). Trees are harvested for sale (and income generation) and/or to satisfy family needs.

Study farms varied widely in size, age and planting densities (Table 1). Most cocoa plantations have already exceeded their economic rotation length and urgently require rehabilitation, the average age of cocoa stands being more than 30 years. The average yield from these traditional systems in the region of Talamanca is about 243 kg ha⁻¹ y⁻¹ and 0.75 kg plant⁻¹ y⁻¹ of dried cocoa (Cruz 1991); these figures were used as a reference in this study. Current level of management in cocoa stands ranges from very poor in some farms to relatively good in others. Poor management was evident especially in relation to pest and disease control, shade management and pruning. Management limitations were of different types and origins, including low yields, diseases (mainly infestation by *Moniliophthora roreri*, a fungal disease), low prices for cocoa in previous years and the type of seed or cocoa genetic material used. All surveyed farms were managed under organic farming standards established by the local cooperative APPTA (Association of small producers of Talamanca). Trees were felled on sites with slopes ranging between 0–30%,

but only in a very small number of cases (4 out of 49) did slopes go above 10%.

Field data

In total, 49 felled *C. alliodora* trees were sampled. Trees were harvested by local farmers between the months of April and June 2001, well after the peak cocoa harvesting period of January and before the beginning of the wet season (late June/early July). Farms were selected on condition that they had laurel shade trees over cocoa and could be visited soon after felling (1 week at the latest) or at the time of felling. Farms were selected from the list of felling permissions issued by local indigenous authorities in 2001.

The field measurements on the farms included: (1) crop spacing and surface area, (2) sketches and brief mapping data of the felling sites, (3) counts of total number of cocoa trees in the farm, (4) counts of damaged and undamaged cocoa plants under each felled tree, (5) a consideration of whether damage was inflicted by either the tree trunk or the crown of each tree, (6) estimation of severity damage level to each cocoa plant under the felled tree; and (7) tree data (diameter at breast height (*d*), total (*h*) and commercial (*Hc*) tree height, crown dimensions (major and minor axis), log volumes and timber volumes).

The criteria used for counting the number of cocoa plants under each felled tree was to include both damaged and undamaged plants that were located

within the area of the felled tree in order to obtain a ratio for damaged and undamaged plants. This included plants which had at least some contact with the surface area occupied by the tree once it was felled. Cocoa plants around the tree stump were also counted as some must be cut to ease tree harvest. Timber volumes were calculated in two different ways depending on the site scenario. In cases where the tree logs were still on the felling site, volumes were calculated per log by using Smallian's formula (Prodan et al. 1997) and then adding all the volumes together. However, in cases where all or most of the tree logs had already been processed and extracted from the site and no data of the extracted log volumes was available from the farm owners, Hc (commercial height) of the harvested tree was estimated. This concerns conventionally merchantable material only and is measured as the distance from the base to the highest point of the main stem before forking and forming a crown. Hc estimation was possible as the tree crowns remained on site after extraction with evidence of the highest processed point on the tree before the spring of the crown (i.e. forking). An approximate figure for Hc was obtained by measuring the distance from the furthest point of the stump to that given point of the crown. Assuming that Hc and d are known, extracted timber volumes were calculated using Lujan's formula (Prodan et al. 1997):

$$V = e^{[(2.03986 \times \log 10d) + (0.779 \times \log Hc) - 4.07682]} \quad (1)$$

where d = diameter at breast height (cm) and Hc = commercial tree height (m).

Following Somarriba and Beer's (1987) criteria, the real commercial volume obtained from farmers was only 64% of the total overbark stem volume. Therefore, taking into consideration possible defects such as buttress roots, stem irregularities, heart rot and forking, and that guided chainsaws were used in situ for the processing of all the surveyed trees (with a consequent lower milling efficiency than conventional sawmills), a 36% volume loss coefficient was applied for timber volume estimation.

Data analysis

Damage data was used to calculate: (1) the frequency distribution of damage per severity level, (2) the percentage of damage caused by either the tree crowns or trunks and (3) the severity of the damage

Table 2 Cocoa yields per damage class and year after damage expressed as a fraction of the unencumbered yield of undamaged plants

Year after damage	Damage class					
	1	2	3a	3b	4a	4b
1	0.00	0.00	0.25	0.40	0.65	0.85
2	0.00	0.30	0.40	0.65	0.85	0.95
3	0.70	0.75	0.65	0.85	0.95	1.00
4	0.82	0.85	0.85	0.95	1.00	1.00
5	0.91	0.95	0.95	1.00	1.00	1.00
6	0.96	0.99	1.00	1.00	1.00	1.00
7	0.99	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00

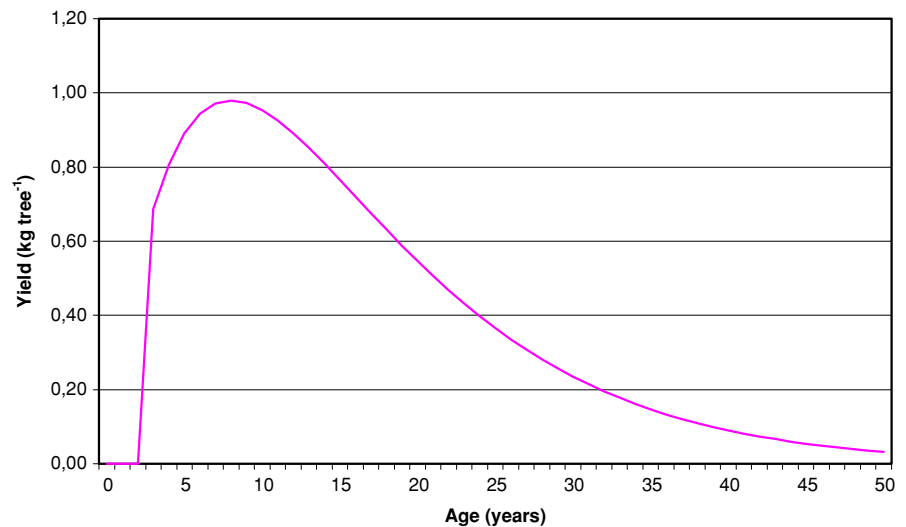
Figures set arbitrarily from consultation with literature and experts on growth and development of cocoa

caused by either part of the tree. Damage to cocoa was translated into yield losses (Table 2) and their corresponding economic values. The present values of net revenues arising from the timber and cocoa produced by the damaged plants (or their replanted or coppiced replacements) during the harvest of one tree, were compared against the present values of future timber net revenues (assuming a 50-year rotation) and the same number of undamaged cocoa plants (i.e. the net gain/loss of income if trees are felled at present and cause damage against the income if not felled at present and therefore cause no damage). Cocoa is a perennial crop and its yield reductions may extend beyond 1 year since damage occurred, hence the use of net present values is warranted. Costs of felling, processing and extraction were also included in the economic data. Costs of different management practices for different damage levels such as replanting, coppicing and pruning were only considered when damage occurred.

Description of the model

A computer model (written in Microsoft Excel XP) was designed to evaluate the economic impact in net present values of damage to crop plants in cocoa plantations with different planting densities, yields and cocoa prices. The model uses four different categories of parameters: tree data (dimensions and volumes), cocoa data (age of plantation and yield), economic data (rates of interest, prices for cocoa and timber, crop management costs, and timber

Fig. 1 Cocoa yield curve over a 50-year period based on Eq. 2: $C = e^{(-1.1 + \ln(A) - 0.125A)}$ where C = cocoa yield and A = age



processing and extraction costs), and data estimating the yield response of cocoa to different damage levels i.e. cocoa yields expressed as a fraction of the expected unencumbered yield (Somarriba 1992). The economic section of the model evaluates the difference between the discounted cash flow streams of the costs and benefits for the cocoa and shade trees with immediate felling of the shade trees and if the shade trees were left to grow until the end of the cocoa rotation. For the shade trees the cash flows are either the immediate revenue from felling less the associated felling and processing costs, based on the current volume, or the discounted revenue and associated costs if the tree is felled in 50 years at an increased volume. For the cocoa, if the shade trees are felled, then the discounted stream of cash flows relates to the changed revenue over the cocoa plants in the different damage categories, the associated costs, as well as the costs of replanting, where necessary. This scenario is compared with the discounted revenue and cost stream if the same cocoa bushes were left undamaged and yield remained on the normal growth curve. The formula applied for the cocoa yield curve (Fig. 1) used in the model was as follows:

$$C = e^{(-1.1 + \ln(A) - 0.125A)} \quad (2)$$

where C = cocoa yield and A = age.

Discount rate was set at 10% and expressed in constant 2001 values. Price of organic cocoa in Talamanca is US\$0.9 kg⁻¹, log market price for *C. alliodora* in the region of study is US\$128 m⁻³, costs

of timber processing (in situ sawing with chainsaws and frame) and timber extraction are both US\$6 m⁻³, and costs of crop management were estimated to be around US\$0.1 tree⁻¹ for pruning, US\$2 tree⁻¹ for coppicing and US\$10 tree⁻¹ for replanting. The average yield of each individual cocoa tree is set at 0.75 kg tree⁻¹ y⁻¹ with a maximum of 0.98 kg tree⁻¹ y⁻¹ (Cruz 1991).

Costs of planting and tending of shade trees were not taken into consideration as it was assumed that farmers selected the trees from natural regeneration, with sporadic thinning related to regulation of shade for the crop and that laurel trees are self pruning. Damage due to log skidding was not considered in this study as the farmers carried the processed timber on their backs.

Simulations

Simulations that calculated the timber price that would balance to zero all the discounted costs and benefits were performed by using damage statistics obtained from field data. Many combinations of different cocoa planting densities, cocoa yields, and cocoa prices were tested for hypothetical scenarios. The comparison between the values obtained in the simulations and the current market prices for timber can help to determine whether the use of timber shade trees is likely to be profitable or not.

The cocoa planting densities and yields selected for the simulations are typical of the area of study,

ranging from poorly managed to well managed plantations. If the simulations indicate that harvest of timber shade trees is profitable on the high yielding, high density plantations, then this will also apply to the low yielding, low density plantations.

Results

Damage statistics

The total number of cocoa plants counted under the felled trees was 532, of which 198 (37%) suffered damage. Tree trunks were involved in 55% of the damage cases (109) and tree crowns in 45% (89). On average, the number of cocoa plants that suffered damage per felled tree was 4.0, of which 2.2 were affected by the trunk and 1.8 by the crown. Although the severity of damage was proportionately higher in those plants affected by the crown than those affected by the trunk, actual numbers severely damaged were higher in the latter. Thus, while replanting and coppicing was necessary for 40% of the plants affected by the tree trunk and for 45% of plants affected by the tree crown, 44 plants affected by the tree trunk required replanting and coppicing compared with 40 affected by the crown. Furthermore, another 32 plants required very heavy pruning in the trunk damage case, whereas this number was only 18 in the case of crown damage. Both trunk and crown caused similar amounts of less severe damage (Table 3). Figure 2 shows the frequency distribution for each damage class as an average per felled tree.

The results did not suggest a fixed pattern of damage and showed exceedingly large standard deviations. There were high variations in the number of plants affected by each tree and the frequency distribution per damage class.

The average laurel tree harvested was 62 cm in d and 35.5 m in h , yielding a total overbark stem volume of 4.4 m³ and a commercial volume of 2.8 m³ of timber. The revenue from immediate timber production was US\$334 per tree compared to a net present value of US\$20.47 if tree harvest was delayed. On the other hand, the average present value of the damaged cocoa (\$7.88) was higher than the undamaged (\$5.41). The resulting gain averaged US\$316 per tree with no cases of net loss in the 49 trees felled. Out of all the reported cases there was a

Table 3 Damage by severity level to cocoa plants statistics due to the harvest of 49 *Cordia alliodora* trees used as shade over cocoa plantations, Talamanca, Costa Rica

By whole tree	Damage level ^a					
	1	2	3a	3b	4a	4b
Plants tree ⁻¹	7	77	50	26	5	33
Percent	4	38	25	13	3	17
Average	0.1	1.6	1.0	0.5	0.1	0.7
St Dev	0.456	1.646	1.010	0.793	0.306	0.747
By trunk						
Plants tree ⁻¹	5	39	32	13	3	17
Percent	5	36	29	12	3	16
Average	0.1	0.8	0.7	0.3	0.1	0.3
St Dev	0.421	0.912	0.855	0.491	0.242	0.522
By crown						
Plants tree ⁻¹	2	38	18	13	2	16
Percent	2	43	20	15	2	18
Average	0.0	0.8	0.4	0.3	0.0	0.3
St Dev	0.200	1.358	0.698	0.531	0.200	0.591

^a Description of damage severity classes

- (1) Uprooted tree, 100% crown loss (requires replanting)
- (2) Snapped off or all primary branches damaged, 100% crown loss (requires regeneration from stump (i.e. coppice)
- (3a) Primary branches damaged, 75–99% crown loss (very heavy pruning)
- (3b) Primary branches damaged, 50–74% crown loss (heavy pruning)
- (4a) Secondary branches damaged, 25–49% crown loss (moderate pruning) and
- (4b) Secondary branches damaged, 0–24% crown loss (light pruning)

minimum net gain of US\$142 and maximum net gain of US\$1,067.

Simulations

For all considered scenarios, the timber market price that would balance discounted costs and benefits to zero ranged from 22 to 66 US\$ m⁻³. Note that the current (2001) log market price for *C. alliodora* was 128 US\$ m⁻³. Therefore, losses could increase up to two times before the farmer's total revenues turned negative due to the harvest of timber trees. The higher the yields and prices for cocoa, the lower the margins for revenue against cocoa damage. Table 4

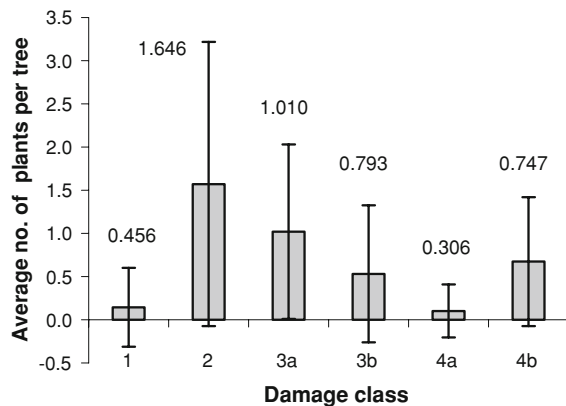


Fig. 2 Average number of damaged cocoa plants per harvested tree. The *diagram* shows the average distribution and standard deviation of biological damage in different classes (see Table 3 for damage class descriptions)

Table 4 Timber breakeven prices (US\$ m⁻³) that would balance discounted costs and benefits to zero in a range of possible prices and yields for cocoa

Cocoa price (US\$ kg ⁻¹)	Cocoa yield (kg ha ⁻¹ yr ⁻¹)					
	125	250	500	750	1,000	1,500
0.25	21.66	21.97	22.59	23.22	23.84	25.09
0.50	21.97	22.59	23.84	25.11	26.33	28.82
1.00	22.59	23.84	26.33	28.82	31.31	36.29
1.50	23.22	25.09	28.82	32.76	36.29	43.86
2.00	23.84	26.33	31.31	36.29	41.28	51.24
2.50	24.46	27.58	33.80	40.03	46.26	58.71
3.00	25.09	28.82	36.29	43.77	51.24	66.18
3.50	25.71	33.28	38.78	47.50	56.22	73.65
4.00	26.33	34.99	41.28	51.24	61.20	81.13

Current (2001) price for *Cordia alliodora* timber is US\$128 m⁻³, cocoa yield in the region of study is 243 kg ha⁻¹ yr⁻¹ and cocoa price is US\$0.90 kg⁻¹

shows the breakeven prices of timber that would balance discounted costs and benefits to zero (i.e. that would give a zero discounted net gain from early felling) for a range of possible prices and yields for cocoa. The price for cocoa in the region at the time of the study (2001) was US\$ 0.9 kg⁻¹ and average yields were 243 kg⁻¹ ha⁻¹ yr⁻¹. The cocoa prices displayed in Table 4 range between the lowest and highest prices recorded since 1960 (ICCO 2003). Yields are increased up to scenarios with 1,500 kg⁻¹ ha⁻¹ yr⁻¹, which is the highest usually achieved in smallholder farms.

Discussion

Concern about damage inflicted by shade trees on the cocoa crop is by no means recent. In 1964, Freeman (cited in Wood 1975) described the properties required of an ideal shade tree for cocoa. One of the most important characteristics he mentioned was ease of removal when finished with. The shade tree should not damage the cocoa canopy when felled and it should be of commercial value (Beer 1987). Our study suggests that, despite farmers concerns (Mussak and Laarman 1989) about the importance of damage to cocoa crops due to timber harvest in cocoa plantations, damage should not be a limitation on the use of timber shade trees. The amount of biological damage inflicted on cocoa plants is limited and the returns from timber sales easily offset reductions in cocoa yields and restitution costs. In old cocoa plantations, cocoa yields may even increase as a consequence of coppicing or replanting low yielding, severely damaged plants and thus accelerating crop renewal.

The economic insignificance of cocoa is largely attributable to the generally old stands which were found in the samples. If, instead, the same levels of damage were to occur within a 9-year old stand (peak yields are achieved at 8–10 years), the average net gain from timber harvesting would be US\$296, compared to US\$316 obtained in practice. Nevertheless, even in this situation, the gain from the timber harvest would still far outweigh the cost of this damage.

Despite occupying a smaller area, the reason why the tree trunk was involved in more damage cases than the crown may be because it forms a more solid and heavier body than that of the crown. However, the results did not provide a fixed pattern of damage and showed exceedingly large standard deviations. This could be related to the fact that harvesting sites varied greatly within and between different cocoa farms as explained in Table 1. Unlike intensive monocultures and research stations, these indigenous farms have a very irregular planting layout. Further research should consider analysing damage in permanent plots with similar planting densities and regular spacing. It is important to know as well that not all trees that are harvested cause damage, for example, when harvested trees fall on areas with low planting densities, neighbouring land, on roadsides and in fallow land.

Either accidentally or due to lack of felling skills, some trees were felled in the wrong direction to the one intended. Damage could be minimised by felling from the farm outwards or to other areas with smaller planting densities of cocoa. If the planting density is the same in all directions around the tree, trees should be felled aiming in between the rows of cocoa. The cocoa or the laurel could be lightly pruned to provide a wider falling space for the timber trees when felled. Harvest should be concentrated during periods of low cocoa prices and/or cocoa yields. In fact, the timing of the harvest in Talamanca depends solely on the onset and duration of the dry season (February–June), which matches the non-flowering phase of the cocoa plantation. Whenever possible, trees should be planted and tended between cocoa rows to reduce trunk damage.

With the cocoa price of US\$0.90 kg⁻¹ used here, or within the approximate range of US\$0.25–3.00 kg⁻¹ experienced over the past 30 years, economic loss of cocoa production is insignificant in relation to the large revenue obtained from timber harvest.

Even when farmers lose up to 36% of the total stem wood volumes because of buttress roots, malformations, forking and poor timber processing skills, the timber revenue far outweighs the costs of damage. Increasing trends in timber prices and the fluctuating prices for cocoa support the use of timber trees to help reduce risk and provide farm stability against market fluctuations in cocoa farming (Ramirez et al. 2001).

The study provided a reasonable estimate of the costs and benefits of incorporating timber trees in the shade strata. However, the estimations of yield change in cocoa and the criteria followed when nominating damage severity levels may not be the most appropriate. More detailed research is necessary on the physiological changes in cocoa and its effects on the overall yield of the plant after different types of damage.

Conclusions

Damage inflicted to cocoa trees by the harvest of *C. alliodora* trees used as shade is not as severe as usually expected. The additional income from timber production can easily offset the costs of the little

damage experienced. The farmer benefits greatly, whether from sales or in meeting their own household needs (e.g. housing and construction), from these home grown sources and the need to gather and look for timber in the surrounding natural forest is reduced. The consideration of damage to crop plants should not be a constraint for the use of timber trees as shade in their plantations.

The computer model used for this study, combining timber and cocoa yield models, costs and prices, a range of damage classes and their effects over time, and discounting, allows consideration of a number of shade tree/cocoa plant scenarios. Although the model does not provide a definite answer concerning whether or not to use timber trees, it does make a valuable contribution to decision making. Further research is needed to increase the sample size and cover a wider range of growing conditions and combinations with other timber shade tree species. In fact, different cocoa-shade tree combinations require specific curves and data which even nowadays is quite scarce, in order to make specific suppositions about the relationship between tree density, cocoa yield, etc.

The outstanding value of the biodiversity of the traditional cocoa agroforests is increasingly being realised. However, a positive economic appraisal is also the most compelling argument for the inclusion of timber shade trees and as a counterargument against the current tendency to eradicate shade trees from intensively managed cocoa plantations.

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